

FAULT DETECTION OF BEARINGS USING CONDITION MONITORING TECHNIQUES

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ABSTRACT

Failure of anti-friction bearings is dangerous as it damages rotating machinery, entails production loss and may cause injuries to persons [1,2]. So, a very important duty of the maintenance department is to prevent these failures in its initial stage. Condition monitoring of antifriction bearings in rotating machinery using vibration analysis is a very well established method. It offers the advantages of reducing down time and improving maintenance efficiency. The machine need not to be stopped for diagnosis [3]. Even new or geometrically perfect bearings may generate vibration due to contact forces between the various components of bearings. Analysis of vibration and sound signature of rolling element bearings is an established tool for early detection of progressing bearing faults. In this paper, an attempt is made to elucidate the defect frequencies and their amplitudes for ball bearings having single and multiple localized defects.

KEYWORDS: Condition Monitoring & Bearing Defects

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INTRODUCTION

The localized defects in antifriction bearings include cracks, pits and spalls caused by fatigue on rolling surfaces. Defective rolling elements in antifriction bearings generate vibration frequencies at rotational speed of each bearing component where rotational frequencies are related to the motion of rolling elements, cage and races. Initiation and progression of flaws on antifriction bearings generate specific and predictable characteristic of vibration. Equations in Ref. [5] may be used to obtain specific defect frequencies due to component flaws (inner race, outer race and rolling elements)

$$f_c = \frac{f_r}{2} \left(1 - \frac{d}{D} \cos \alpha \right) \quad (1)$$

$$f_o = \frac{zf_r}{2} \left(1 - \frac{d}{D} \cos \alpha \right) \quad (2)$$

where f_r , f_c are the rotating frequency of the shaft and the cage, respectively in Hz, d is ball diameter, D is the pitch circle diameter, z is the number of balls, α is the ball contact angle, f_o is the defect frequency of outer race.

Multiple Defects

In case of ball bearings with multiple defects a certain pattern of pulse trains is formed by individual pulses as a result of the respective defects with the same recurrence frequency. Therefore, the synthesized

pulse train is related to the defect interval angle. Since, this defect interval angle is assumed to give rise to time delay (this is, the time difference in vibration pulse occurrence) the equation for calculating its reciprocal is obtained. Following [6], the interval angle ϕ between two defects on the outer raceway of a ball bearing may be expressed as in (5).

$$\phi = \varphi + k\varphi_0 \quad (3)$$

where φ_0 is the ball interval angle, and k is 0 for $\phi < \varphi_0$ (or) a positive integer, when $\phi > \varphi_0$. For $\varphi = \varphi_0$, ϕ is an integral multiple of φ_0 and for this case the pulses due to the defects occur simultaneously without any time delay. However, when $0 < \varphi < \varphi_0$, that is, when ϕ is not an integral multiple of φ_0 , the pulses due to the two defects have a delay; one follows the other with a time delay τ . The reciprocal of τ is denoted by $f_{\tau o}$ (Hz) and is given in (6), where z is number balls, and f_o is the defect frequency of outer race.

$$f_{\tau o} = \frac{\varphi_0}{\varphi} f_o \quad (4)$$

Experimental Setup and Measurements

Vibration and sound measurements are performed on a test rig (Figure 1(a)) in which the test bearings (SKF 6202, deep groove ball bearing with 15 mm bore and $\varphi_0 = 45^\circ$) are mounted at the end of the shaft, which extends into acoustic chamber. The test bearing specifications are taken from Ref. [7]. The support bearings in the rig are pre-lubricated deep groove ball bearings with 25 mm bore, and sealed at both ends. For measurements, the test bearings are run at a speed of 750 rpm with a radial load of 10 kg applied by a lever type arrangement (Figure 1(b)). Three good bearings (without any defect) were initially tested to record their vibration levels for the sake of comparison. Defects were introduced next by creating circular holes (1 hole for single and 2 holes for multiple defects) of 1 mm diameter on outer raceway by spark erosion. Experiments with single and two defects were done in steps where the angles between two defects are selected as $\phi = 20^\circ (< \varphi_0)$, $\phi = 45^\circ (= \varphi_0)$, and $\phi = 60^\circ (> \varphi_0)$. For this the bearings were mounted on the test rig with the defect in the outer raceway located in the zone of maximum load. Vibration signals from bearings were recorded on an ONO SOKKI CF-3200 FFT analyzer through a charge amplifier. The frequency range for the measurement of vibration and sound are from 0 to 100Hz. In case of sound pressure measurement, a Bruel and Kjaer microphone type 4165 (sensitivity 50 mv/pascal) was used.

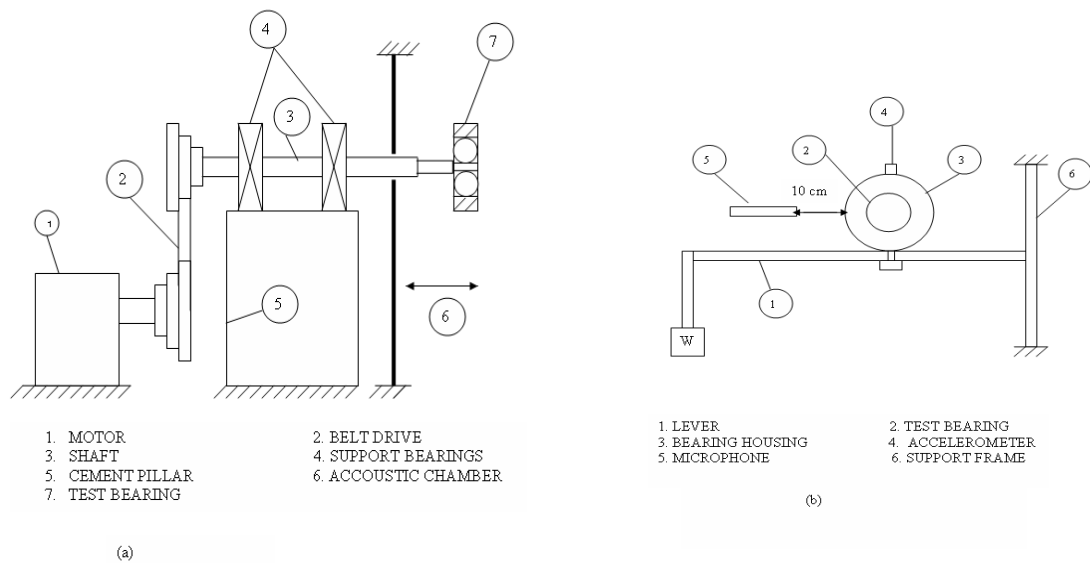


Figure 1: A Schematic Diagram of (a) the Test Rig; and (b) the Loading Arrangement.

RESULTS AND DISCUSSIONS

Figure 2 shows the spectrum of a good bearing with little peak (0.12 mm/s) at the defect frequency of 38 Hz. Figure 3 shows the spectra, when there is one defect. A comparison with Figure 2 shows higher amplitude (0.25 mm/s) at the defect frequency. For a bearing with two defects separated at 45° ($k = 0$ and $\phi = \phi_0$) Figure 4 shows the spectrum, where an amplitude of 0.37 mm/s is seen at the defect frequency. A higher amplitude compared to that in Figure 3 is due to the coincidence of pulses as $\phi = \phi_0 = 45^\circ$. Figure 5 shows the spectrum of a bearing with two defects at a separation of 60° ($\phi > \phi_0$, $\phi = 15^\circ$, $k = 1$, $\phi_0 = 45^\circ$). As the defect separation angle is not equal to the ball separation angle of two peaks (of amplitude 0.323 mm/s each) are seen to occur at 38 Hz and 153.78 Hz i.e., at a difference of $f_{\tau_0} = 115.78$ Hz, which marginally differs from the calculated value of $f_{\tau_0} = 114$ Hz from equation (4). Figure 6 shows the spectrum where two defects are located at a separation of 20° ($\phi < \phi_0$, $\phi = 20^\circ$, $k = 0$, $\phi_0 = 45^\circ$). As before two peaks (of amplitude 0.32 mm/s each) are seen to occur at 38 Hz and 125.27 Hz, i.e. at a difference of $f_{\tau_0} = 87.27$ Hz which marginally differs from its calculated value of 85.5 Hz from equation (4).

Measurement of sound pressure level was also carried out; Figures 7 and 8 show the sample spectrums to save space. In Figure 7 the two peaks at the defect frequency of 38 Hz (amplitude 32.3 dB) and at 153.7 Hz (amplitude 33.4 dB) i.e., at a difference of 115.7 Hz which is marginally differs from calculated value of 114 Hz. In Figure 8, the two peaks at the defect frequency of 38 Hz (amplitude 33.2dB) and at 124.42 Hz (amplitude 32.6 dB) i.e., at a difference of 86.42 Hz instead of 85.5 Hz as calculated before.

Figure 9 shows a bar graph of vibration amplitudes at defect frequency of 38 Hz for different cases. This clearly shows that single defect generates the least amplitude; the same is the highest if two defects are separated the same angle as the balls, as the pulses occur simultaneously and add to the power of the component, and the amplitude is in between these when the defect separation angle differs from the ball separation angle. However, the occurrence of defect frequency due to

the second pulse and the amount of separation are distinctive features of multiple local defects with an angular separation not equal to that of the balls.

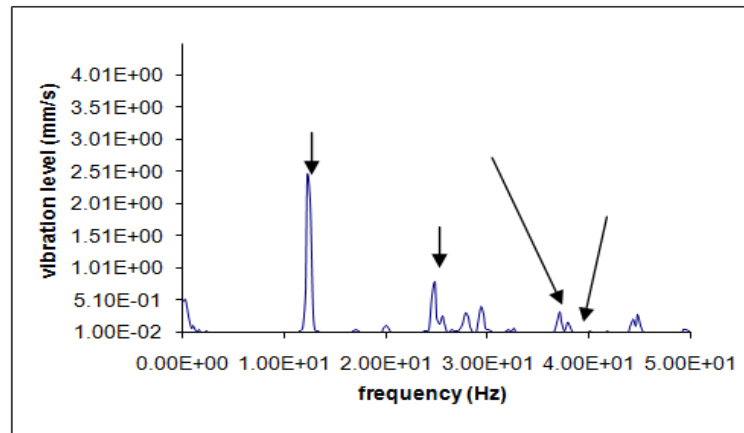


Figure 2: Vibration Spectrum of Good Bearing at 750 Rpm, 10 Kg Load.

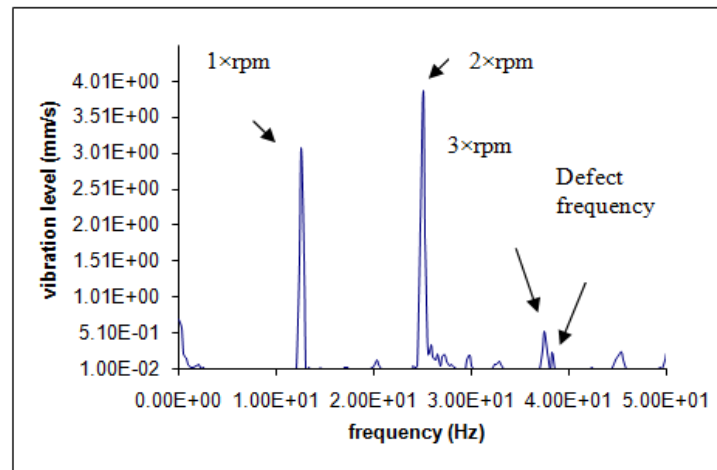


Figure 3: Vibration Spectrum of Single Defect Bearing at 750 Rpm, 10 Kg Load.

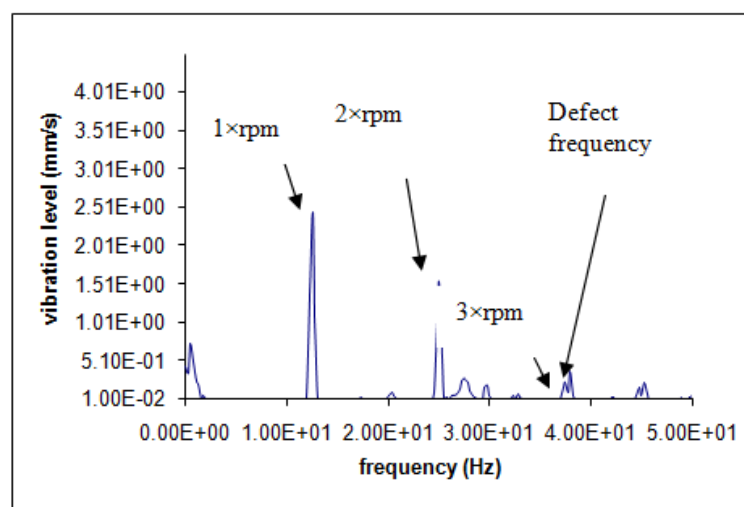


Figure 4: Vibration Spectrum of Multiple Defective (45°) Bearing at 750 Rpm, 10 Kg Load.

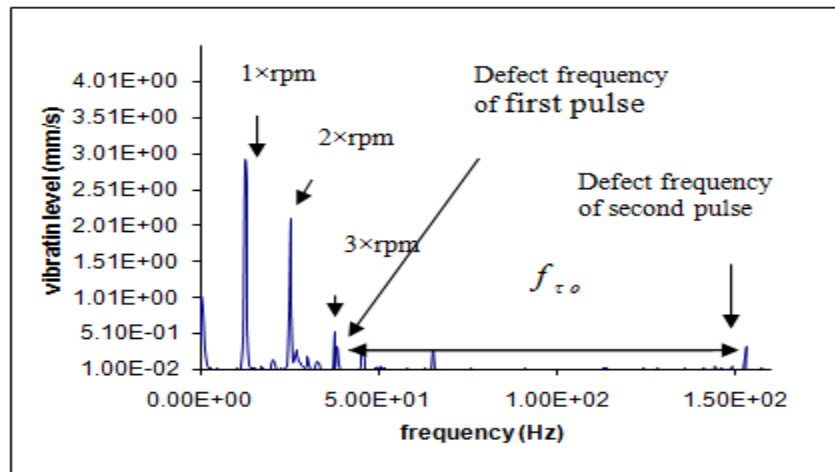


Figure 5: Vibration Spectrum of Multiple Defective (60°) Bearing at 750 Rpm, 10 Kg Load.

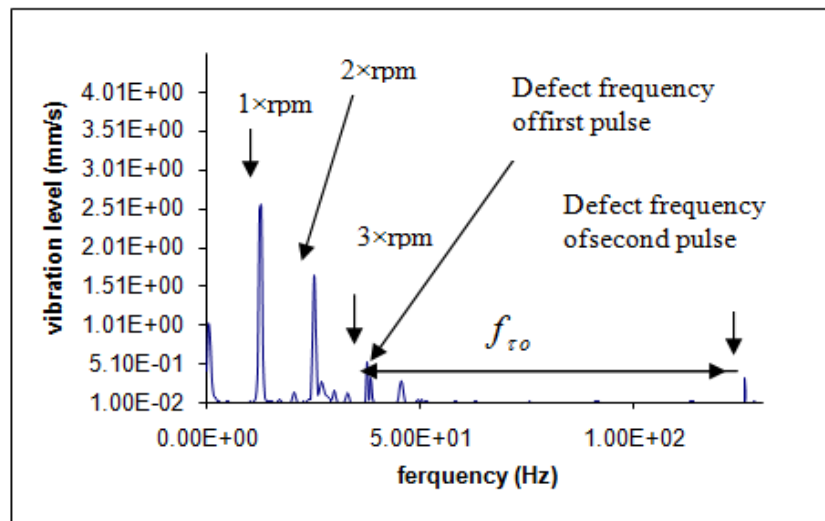


Figure 6: Vibration Spectrum of Multiple Defective (20°) Bearing at 750 Rpm, 10 Kg Load.

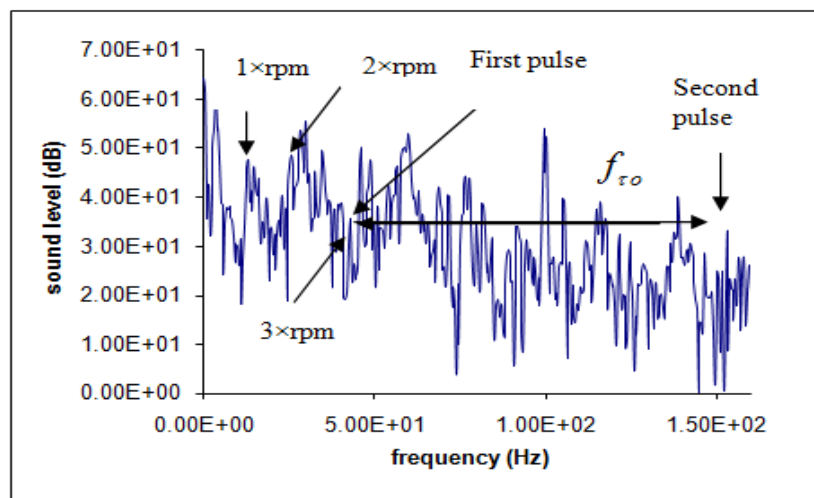


Figure 7: Sound Spectrum of Multiple Defective (60°) Bearing at 750 Rpm, 10 Kg Load.

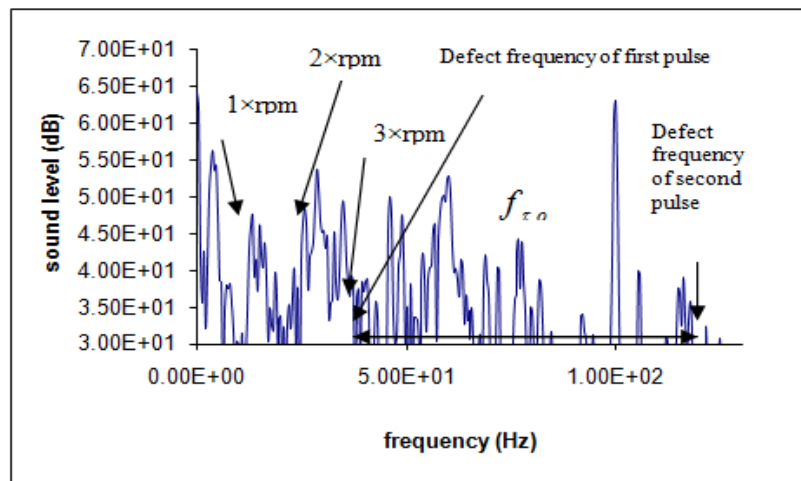


Figure 8: Sound Spectrum of Multiple Defective (20°) Bearing at 750 Rpm, 10 Kg Load.

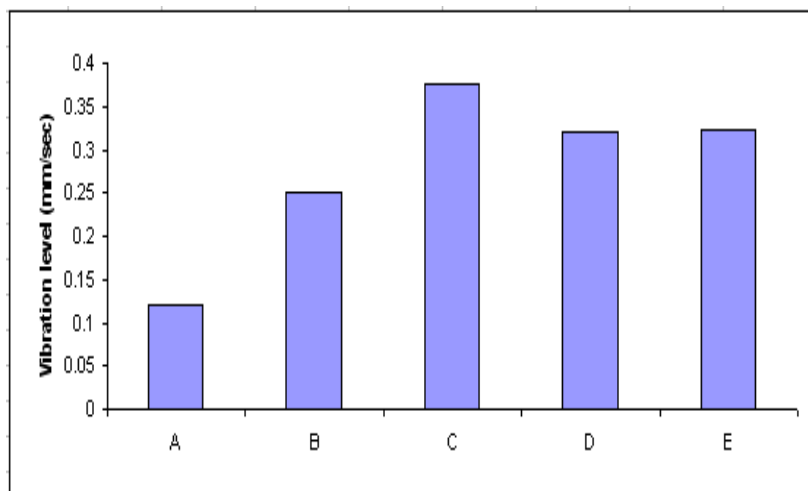


Figure: 9 Vibration Amplitudes at Defect Frequency of Different Bearings
A. Good bearing, B. Single Defect Bearing, C. Multiple Defect (45°) Bearing,
D. Multiple Defect (60°) Bearing, E. Multiple Defect (20°) Bearing.

CONCLUSIONS

- In this paper frequency analysis of vibration and sound pressure signals has been used to identify single and a couple of local defects in the form of surface cracks, pits or spalls on the outer raceway of deep-groove ball bearings.
- Single defect increases the spectral component at the defect frequency, a couple of defects if separated by the same angle as the balls, increase the component at the defect frequency further and the defects, when separated by an angle unequal to the angle between two balls, introduce another spectral component, called the 'defect frequency of the second pulse'.
- So, the occurrence of a defect couple separated by an angle not equal to the ball separation angle is easily identifiable, however, the occurrence of single defect or a couple separated by an angle same as the ball separation angle may not be easily distinguished; ranking the amplitude level at defect frequencies as a function of defect size may prove to be a very useful approach.

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